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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

ETL 1110-2-553

Technical Letter
No. 1110-2-553

30 May 1997

Engineering and Design
CONTROL STATIONS AND CONTROL SYSTEMS
FOR NAVIGATION LOCKS AND DAMS

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Report Documentation Page

Report Date 30 May 1997	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle Engineering and Design: Control Stations and Control Systems for Navigation Locks and Dams	Contract Number	
	Grant Number	
	Program Element Number	
Author(s)	Project Number	
	Task Number	
	Work Unit Number	
Performing Organization Name(s) and Address(es) Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	Performing Organization Report Number	
Sponsoring/Monitoring Agency Name(s) and Address(es)	Sponsor/Monitor's Acronym(s)	
	Sponsor/Monitor's Report Number(s)	
Distribution/Availability Statement Approved for public release, distribution unlimited		
Supplementary Notes		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 13		

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CONTROL STATIONS AND CONTROL SYSTEMS
FOR NAVIGATION LOCKS AND DAMS**

1. Purpose

This Engineer Technical Letter (ETL) describes current usage and provides guidance for future designs of control station structures and control systems for navigation locks. The primary intent of this ETL is to require cost-efficient control stations and to encourage the use of programmable logic control systems rather than relay-based systems.

2. Applicability

This ETL applies to all HQUSACE elements and USACE commands having responsibilities for Civil Works projects.

3. Background

a. The primary purpose of navigation locks and dams is to provide navigable depths by damming of the waterway, thus allowing transfer of navigation vessels from one water level to another in a safe, reliable, and expeditious manner. To perform this complex operation, lock operating personnel must be provided with convenient control stations containing dependable operating control systems that can be easily operated, maintained, and modified. These operating systems also need to be designed so that they can be upgraded to incorporate advances in technology.

b. The Corps, in its stewardship of the inland waterway navigation system, has entered into a period where:

- More double locks are being constructed.
- New electronic technology with automated operating systems and equipment are available.
- Future advances in electronic technology will allow opportunities for incorporation of improved operating systems.
- Personnel limitations are reducing the number of lock operating and maintenance personnel so that some locks have only one operator and some shifts are not staffed.
- Increasing traffic demand for lockages may tax operating equipment due to the ever increasing frequency of operation of the equipment.
- Initial and future costs must be carefully considered for life cycle efficiency of navigation project construction, operation, maintenance, and major rehabilitation.

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c. Therefore it is timely to review past practices and formulate guidance for future layout of lock

control stations and design of lock and dam control systems.

FOR THE COMMANDER:

2 Appendices
APP A - Lock and Dam Control Stations
and Control Systems
APP B - Operation of PLC Systems

A handwritten signature in black ink, appearing to read 'S. L. Stockton', with a stylized, flowing script.

STEVEN L. STOCKTON, P.E.
Chief, Engineering Division
Directorate of Civil Works

Appendix A

Lock and Dam Control Stations and Control Systems

A-1. Lock and Dam Projects

a. Introduction. There is a wide diversity of navigation projects on the inland waterway system. The differences lie in the configuration of the lock with respect to the dam, the waterway traffic on the system, the existence of hydropower or flood control storage, and the hydrology. Because of these differences, a wide range of lock configuration and operating characteristics has evolved. These include; electrical-mechanical operating equipment, lock and dam control systems for the operation of gates and valves, number and location of control stations, number of people required to operate the navigation project, method of observation of vessel approach and egress, communication with pilots, mooring assistance to vessels, and methods of data management.

b. Lock configuration. There are three lock configurations: single locks, double locks (either separated or side by side), and tandem locks. Any of these locks can be adjacent to or separated from the navigation dam, or they may be located in a navigation canal. Locks are usually located with the upstream gates in line with the dam axis.

(1) Single lock. The single navigation lock is by far the most predominant type at existing Corps projects. It consists of one single lock either isolated in a canal or associated with a dam in a river.

(2) Double locks (side by side). Most existing side-by-side locks consist of a long main lock and a shorter auxiliary lock. However, some projects (Smithland Locks and the Olmsted Locks currently under construction) have twin 1,200-ft side-by-side locks.

(3) Double locks (separated). This configuration is provided for operational efficiency, capacity, cost, and safety. The separation is intended to provide for improved traffic capacity since two tows can make simultaneous approaches and departures. Melvin Price Locks and Dam in the St. Louis District is the first project constructed with a separated configuration.

(4) Tandem locks. A tandem lift lock consists of one long segmented lock chamber with intermediate gate locations to provide a high lift in incremental steps. Tandem lift locks have been provided at locations where the lift was too large to practically accomplish a lockage in a single lift. There are only two Corps projects in the continental United States with operational tandem lift locks. The Wilson Lock on the Tennessee River in the Nashville District, which opened in 1927, has one auxiliary lock with two lock chambers and three control stations. The Willamette Falls Locks on the Willamette River in the Portland District, which opened in 1873, has five stair-stepped lock chambers and three control stations. It was originally a privately owned lock and was later purchased by the Federal Government. Another two-chambered tandem lock, Little Chute, on the Fox River in Wisconsin was opened around 1879 but is no longer in operation.

c. Lock control station locations.

(1) Local control. On most of the single locks constructed since the 1930's, the lock operating controls are located in two small structures on top of one of the lock walls; one near the upper and one near the lower gate recesses. This type of control is referred to as **local control** since the controls are located adjacent to the lock gate to be operated.

(a) At most single locks, local control stations are located on the land wall of the lock for convenience of access by lock operating personnel, since the operating, administrative, and maintenance facilities are generally located on or adjacent to the land wall. However, at some existing locks, where the lock operator has additional duties related to the adjacent dam and/or power plant or other nearby project facilities, the control stations are located on the river wall which is more convenient to all of the component facilities. Interviews with some lock operating personnel indicate that it is their desire to be isolated from the visitors and their activities at or near the land wall. This could be another reason for locating the control stations on the river wall. Some of the older single locks have four local control stations, two on each wall, located at or near the gate recesses.

(b) The land-side lock of double side-by-side locks usually has two local control stations located on the lock walls similar to those described above for

single locks. The local control stations for the river lock are generally located on the common middle lock wall. However, some double locks of this type may have five local control stations; two located on the common middle wall, two located on the land wall, and one located on the shorter river wall. The Smithland Locks have twin 1,200-ft-long lock chambers with four control stations located on the common middle wall. The two upstream control stations are located near the gate bay recesses for each lock.

(c) At projects where additional locks have been constructed, control stations are retained on the original locks and new control stations are added to the new lock. Some of these lock projects are Bonneville, Gallapoli, Pickwick, and some of the Monongahela River locks. These lock structures, old and new, have local control stations located on the lock walls of each individual lock.

(d) The Wilson Lock on the Tennessee River in the Nashville District has one auxiliary lock with two lock chambers and three control stations. The Willamette Falls Locks on the Willamette River in the Portland District has one lock with five chambers and three local control stations.

(2) Central control.

(a) The six single locks on the canal section of the Tennessee-Tombigbee Waterway in the Mobile District, placed in operation in 1985, have the lock operation controls in a control room on the second floor of the operations building that is located on or adjacent to one of the lock walls and just downstream from the dam embankment. This type of station is referred to as a **central control station**. All lock gates and culvert valves are controlled from this central control station. Bay Springs Lock has, in addition to the central control station, two fixed local control stations on the lock wall. One is located at the upper miter gate recess, and the other is located at the lower miter gate recess. It should be noted that the Bay Springs Lock contains the pool for the divide cut, and special measures were needed to ensure safe operation of this project so as not to lose this pool (Pickwick Lake). The other five locks on the Tennessee-Tombigbee have one other auxiliary operating position aside from the central control station. It is referred to as a **local control point**. The local control point consists of a control panel and is located at the lower miter gate recess. This control panel has a

hinged cover and is pipe supported (Figure 1-1). The fixed panel contains controls for the lower miter gate only. The culvert valves are not operated from this location.



Figure 1-1. Local control point

(b) The five new single locks on the Red River Waterway in Louisiana (Vicksburg District) have a central control station similar to the Tennessee-Tombigbee locks. These locks have two portable local control stations on the lock wall with pedestal mountings. These pedestal mounted controls can be removed when the walls are overtopped by flood waters.

(c) The Melvin Price Locks and Dam is composed of one 110-ft-wide by 1,200-ft-long main lock and one 110-ft-wide by 600-ft-wide auxiliary lock separated by two dam spillway bays. The 350-ft separation between lock chambers allows tows to make simultaneous approaches and departures from either lock. The single centralized control station (Figure 1-2) is located in a house high above the service bridge on the tainter gate pier midway between the two locks. Both locks and all the dam gates are controlled from this central control station. A total of eight local control stations are also provided at the four corners of the two separated locks for local operation during maintenance activities and for emergency situations. An interim control station, located on the river wall of the main lock adjacent to the spillway pier and just downstream of the service bridge, provided centralized operation of the main lock during construction of the auxiliary lock but was decommissioned upon completion of the project.



Figure 1-2. Melvin Price Lock central control house

d. Control structures.

(1) Central control station. The central control station is often a large, reinforced concrete structure with architectural treatment of the exterior walls (other construction types may be used). It is sometimes a part of a multi-use (administrative, operations and maintenance, and visitor) building and is always located to provide a clear view of the tows and the lock operations. Closed circuit television (CCTV), communication devices, supervisory operation and control, data collection, and surveillance features are normally provided for safe and efficient lockage control.

(2) Fixed local control station. These buildings contain the control equipment to operate adjacent gates and culvert valves or even to control operation of the entire lock. They have been constructed in place or have been pre-engineered and prefabricated. These structures are sized for the control panels necessary for the lock operation and, if needed, controls for bridges, emergency closures, and other equipment such as CCTV, computers, furniture, bathroom facilities, and, possibly, provision for future control systems. Heating, ventilation, and air conditioning systems (HVAC), where provided, are placed on the roof or in the side wall of the smaller structures.

(3) Portable local control station. The portable local control station is a similar structure to many commercial prefabricated buildings used as parking lot shelters or toll booths. It is designed to be

removable and is normally procured by performance type specifications showing dimensions, loadings, materials, and other requirements such as HVAC, lighting, insulation, and hardware.

(4) Special provisions. In cases where the lock walls are subject to overtopping by flood waters, the structures and controls have been designed so that they are elevated or can be completely removed prior to the flood. In other cases, bulkheads have been provided to protect the controls and equipment from flooding.

A-2. Control Systems

a. Introduction. There is some disagreement over the extent to which computer technology can or should be utilized for command and control of navigation locks and dams. The degree of human intelligence that can be replaced by automated expert systems necessary to supervise and command the operation of a navigation project is debatable. While some projects are fully or partially computerized, others are not computerized at all. Further, there can be confusion when comparing computerized systems to traditional relay systems. This chapter puts the issue in focus by defining terms and presenting a historical perspective of the evolution of relay-based and computer-based control systems within industry and the Corps of Engineers. Data is presented to compare the cost of the two systems for several hypothetical lock and dam configurations. Finally, conclusions are reached as to the applicability of computer-based systems to control navigation projects. The semi-automated control system presented in this chapter assumes that lock and dam command and control operations are initiated and supervised by onsite personnel.

b. Terminology.

(1) PLC system. The computer-based systems utilize special purpose computers called **programmable logic controllers (PLC)**. The PLC performs digital logic operations and was designed specifically by the electrical industry for industrial use. Therefore, for purposes of this document, a computer-based system is referred to as a **PLC system**.

(2) Relay-based system. The traditional **relay-based system (RBS)** relies upon electrical/mechanical relays to perform the logic necessary to control equipment. It is sometimes referred to as a

“hardwired” system because of the many wires and cables which must be routed and terminated. However, this term will be avoided, since a simple manual off-on switch with no relays or logic at all can also be referred to as a hardwired system, and, even in the PLC system, there is some hardwiring.

c. Relay-based control systems.

(1) History. Primitive relay systems were first used commercially by telegraph companies in the 1800's. This simple technology has been in use for decades to control the operating equipment at locks and dams. The typical locks and dams constructed prior to the 1960's utilized RBS's which were housed in custom-made switchboards. The control systems were operated at 480 volts to reduce voltage drops and capacitive coupling effects encountered in long control circuits. This control voltage is considered extremely dangerous and has been eliminated from standard design practice since the early 1960's. Recently installed RBS's are usually operated at 120 volts.

(2) Description. An RBS performs logic operations through the use of numerous electrical/mechanical relays with coils, armatures, springs, and contacts. When the relay is energized, a magnetic field produced by the current flowing through the coil moves the armature which, in turn, causes the contacts of the relay to change state. When the relay is de-energized, the contacts again change state by spring action. Through the use of multiple relays, a logical pattern can be created through the interconnection of the relay coils and contacts. Each relay coil and/or contact is connected to another contact or relay coil through a pair of wires. Since most relays have only three or four sets of contacts, large numbers of relays and contacts are required to create a complex logic system.

(3) Evaluation. While safer to operate and maintain, a 120-volt system requires the addition of more hardwiring and relays. Therefore, adhering to modern safety standards for control voltages requires a much more costly and complex relay system just to duplicate the functioning of the earlier locks. The design is further complicated by requirements for additional interlocking features to prevent damage to operating equipment and machinery.

(a) The switchboards necessary to contain the relay-based equipment need to be custom made,

greatly increasing the cost of fabrication. The industry has established a standard enclosure for motor control equipment which is referred to as a motor control center. These centers are constructed of standardized modular units which can be quickly assembled and wired in the factory. However, because most of today's control systems of any complexity are PLC-based, the standard size of a given motor starter cubicle is not large enough to house all the relays required. Thus, if a complex system is designed using relay logic, custom fabrication is required to house the equipment. RBS's have been the 20th century workhorse of industry. Electricians have worked with this equipment over the years and are familiar with the operating principles and the required troubleshooting and maintenance procedures.

(b) An RBS requires a significant amount of maintenance. As these systems age, relay coils fail, contacts freeze together, wires vibrate loose, and terminals corrode. System reliability is inversely proportional to complexity; the more relays, coils, wires, and contacts, the greater the probability one of these components will fail. Interlocks are routed all over the lock, and a fault can occur anywhere, thus requiring considerable time to locate. Troubleshooting a relay-based control system requires that an electrician take a meter from point to point, sometimes over the whole breadth of the structure, to find the problem. This takes time and could expose the electrician to energized electrical circuits.

(c) RBS's are also very inflexible to upgrades. Logic changes, when necessary, require major modifications to the components. Relays must be physically removed and replaced, requiring time-consuming and expensive control panel modification or replacement. Changes in the logic can also require modification and addition to the cable and raceway systems.

d. PLC systems.

(1) History.

(a) Around 1970, the PLC was developed by the automotive industry to replace the inflexible, expensive, high-maintenance relay systems. By the mid to late 1970's, PLC's were finding their way into industrial control systems nationwide. With the PLC's came a new age in control system design. Initially, PLC processor memories were limited, but, for the first time, complex control systems could be created and changed by simple programming

techniques. This made the cumbersome relay panels and mazes of wire and cabling obsolete, similar to the obsolescent mechanical calculators in favor of electronic computers.

(b) As microprocessor technology evolved, the PLC capabilities were upgraded to take advantage of these advances. PLC's were no longer just relay replacers. They became capable of accepting a wide variety of feedback electrical signals which permitted them to monitor and control electrical equipment such as motors, temperature sensors, pressure sensors, vibration sensors, motion detectors, lights, horns, solenoids, etc.

(c) In the 1980's, software was developed which permitted the PLC to communicate with personal computers. The merging of these two devices revolutionized operator interfaces. Hardwired control panels with pushbuttons, switches, lights, and meters became obsolete in favor of computer-screen images of these devices. The PLC's communicate with the computers over local area networks using digital signals transmitted over fiber optics. Operators can now perform control actions by clicking on an image with a mouse or using a touch screen. The personal computers can be hardened for greater reliability and, if so, are referred to as *industrial personal computers (IPC's)*. Use of computers has improved flexibility since changes to operating instructions and control configurations can be implemented by simply programming new computer code. No physical changes need be made to the system. Reprogramming can be accomplished offsite with new operating code transmitted to the IPC by telephone modem.

(2) Description.

(a) The PLC consists of two sections: the central processing unit (CPU) and the input/output (I/O) modules. Logic operations and arithmetic manipulations are performed in the CPU just as in any other computer. Communication with the electrical field devices is through I/O cards located on the I/O modules. A variety of plug-in cards are available to accommodate the different types of electrical signals encountered.

(b) The I/O cards are where all the thousands of conductors from the field devices are terminated. Since the I/O cards can be remotely located from the CPU, and are usually strategically located around the facility to be controlled, it is possible to reduce

control voltages to nonlethal levels, typically 24 volts. Also, because signals between the I/O cards and the CPU can be digitally multiplexed, the signals can be sent across one fiber-optic cable, eliminating the need for the numerous long cable runs and raceways found in the relay-based systems.

(c) The latest PLC systems have the ability to directly communicate (without the I/O modules) with traditional devices such as motor control centers, transfer switches, power and lighting panels, AC and DC motor drive systems, position tracking equipment, and IPC control stations. The trend in the industry is toward integrated and intelligent power distribution and control systems.

(d) The PLC can be programmed through the use of the IPC. An advantage to this method of accessing the PLC is that, through the use of another personal computer and a modem, an engineer in the district office, or anywhere for that matter, can assist field maintenance personnel when changes or troubleshooting are necessary.

(e) The programming language for the PLC was specifically designed for electrical engineers and electricians in the industrial controls field. The language is composed of symbols similar to those the engineer and electrician were accustomed to seeing in conventional relay ladder schematics. The concept of a relay and its contacts was maintained. The only difference is that, instead of being a physical relay, it now exists only as a software relay internal to the PLC and can be displayed graphically on the computer monitor.

(3) Evaluation.

(a) PLC systems have emerged as the system of choice for industrial control systems of any complexity. The PLC has proven superior to relays in all but the simplest systems. Systems with as few as five or ten relays can usually be economically replaced with PLC technology. Control systems at locks and dams far exceed the minimum criteria for economical application. The PLC easily and economically permits the development of control systems of virtually unlimited complexity. Complex systems are developed by typing in code on a keyboard and can be reprogrammed in a matter of keystrokes.

(b) There is no perfect physical system, however. PLC's have their own unique vulnerabilities.

As with all solid-state devices, PLC's must be operated within their temperature and humidity limits and protected from the accumulation of dust and from lightning- or power-system-induced voltage surges. Manufacturers have developed enclosures and devices to compensate for these limitations and provide protection in most industrial environments. PLC's are suitable for application in the typical lock and dam environment when properly specified.

(c) PLC's have been programmed with expert self-diagnostic programs to assist maintenance personnel when problems occur. Because of their modular construction, repair usually involves the simple replacement of a modular component which should be available from a spare parts inventory onsite. More commonly, the source of the problem is external to the PLC and involves one of the field devices, such as a limit switch which has vibrated loose. Often the problem can be conveniently identified by troubleshooting the system from the comfort of a computer terminal. Through the use of a modem, field personnel can tap into resources from the electrical engineer at the district office to assist in the troubleshooting effort.

e. Comparative costs.

(1) First costs. There is a decided economic advantage in favor of the PLC systems. Most of the higher cost of the RBS is due to several factors: the large amounts of cable and raceways, the cost to furnish, mount, wire, and enclose the numerous relays, and the costs to hardwire the control consoles. There are also structural costs associated with the increased space requirements necessary to accommodate the additional relays compartments, interconnecting wiring, conduit, cable trays, etc. These costs could be significant.

(2) Life-cycle costs. The economic advantage of the PLC would be expected to increase if life-cycle costs were calculated. The PLC would require less maintenance and would increase system reliability. Its flexibility would reduce costs to implement changes to the system. One of its biggest assets, however, is the ability to monitor, detect, and protect against abnormalities and malfunctions in machinery and gate operation.

f. Conclusions.

(1) RBS disadvantages. For design of modern lock control systems, there is no reason to consider RBS's, just as there is no reason to design a mechanical adding machine. Compared to PLC systems, they are extremely difficult and expensive to incorporate changes and quickly become unwieldy and less reliable as their complexity increases. While it is still possible to design an RBS to control a lock, it will be more expensive to fabricate, it will be limited to the capabilities of 1960's technology, and, with current safety requirements and levels of interlocking, it has become obsolete technology. There will eventually be no knowledge or skill base to implement changes, and finally, it may become an electrician's nightmare to obtain and maintain parts.

(2) Current technology. PLC systems provide the opportunity to do things differently; to do things which have been heretofore impossible with relay systems. PLC systems are limited only by the creativity of their designers and the budget or policy constraints under which the designers function.

(3) Training. The need for training of maintenance personnel and the development of in-house electronic engineering expertise to design and modify PLC systems are essential for these systems to successfully function as intended. This is a relatively new, more complex technology requiring higher levels of technological skills from operators, maintainers, and designers. It is unrealistic to assume that a PLC system can be successfully designed, built, and turned over to personnel experienced on the older systems without significant training for the electricians for upgrade to electronic technicians and without qualified electronic engineering support during the transitional period. Without a management commitment to personnel, funding, training, and support, the system will not be successfully implemented. Policy for the implementation of the PLC system should be a top down decision.

A-3. Guidance

a. General. Control systems and associated structures for operating navigation locks can be designed for different levels of technology, depending

on the usage of the project. Locks with low volumes of commercial traffic and high volumes of recreational use may be designed for local control capabilities where it is necessary for lock operating personnel to be physically present on the lock wall in order to move to the upstream and downstream control stations to closely supervise the lockage of small craft. Even though a local control operating system is selected, the control system should incorporate the PLC system. Locks with a high volume of commercial traffic on main stem river navigation systems should be designed for a central control station containing centralized supervisory and control equipment to operate all lock and dam equipment using automated PLC systems. Locks with intermediate levels of commercial traffic volume can be designed for a combination of local and centralized control systems, depending on the mix of commercial and recreational traffic. Each project needs to be analyzed for site-specific conditions during the planning and design of the operating system, considering the factors in Paragraph 3-3.

b. Control systems. The advantages of PLC systems discussed in Chapter A-2 include both first and life-cycle costs; the ability to prevent damage to machinery through more sophisticated monitoring and control techniques, the flexibility to develop control systems of virtually unlimited complexity, the safety of the low voltage PLC system versus the high voltage RBS, and demonstrated reliability. Thus, it is appropriate to design operating systems for major navigation projects using a PLC operating system in a central control station supplemented by fiber-optic networks, CCTV, electronic communication, and computerized data collection capabilities. For smaller navigation projects, local control PLC capabilities with provision for future centralized control should be incorporated. RBS's should be considered only when there is a demonstrated lack of expertise to design or maintain a PLC system.

c. Central control stations.

(1) Justification. Central control for navigation lock projects should be used when justified, based on the comparison of the cost for a large central control structure versus the savings that can be realized over a more labor-intensive system of local control stations. Factors to be considered are:

(a) Number and type of operations required to be accomplished at the project; for example, operation of

two locks, operation of the dam, and operation of hydropower facilities.

(b) Traffic demand; that is, number of lockages, annual tonnage, and size of tows.

(c) Types of traffic; that is, commercial tows and recreational craft.

(2) Features to be considered.

(a) Operations, maintenance, and administrative functions should be combined in a single building.

(b) The central control station should be located above the lock wall to provide maximum visibility for viewing lock operations and to keep the operations above flood elevation.

(c) The central control station should contain monitors for CCTV cameras to observe tow approach, clearance of the tow from the gates, debris or ice in the gate recesses, and correct mitering of the gates before filling or emptying. Radar systems can provide location of approaching tows during inclement weather conditions.

(d) A surveillance system should be provided for security of the installation, especially with a minimum lock staff manning the structure. The security systems can consist of security fencing, remote electronic monitoring, alarm systems, motion detectors in sensitive areas, CCTV surveillance systems, sound monitoring of visitor areas and access points, and gated entry points that can be activated from the central control station. All security systems should be controlled from the central control station.

(e) Provision should be made for centrally operating other features of the project such as the dam gates, power-house equipment, and associated facilities such as drawbridges.

d. Local control stations. In cases where the outcome of the comparative studies does not favor centralized control, fixed local control stations can be provided. No more than two fixed control stations for a single lock chamber or four for a double lock chamber should be provided. Only one of the control stations should be equipped with personnel comfort facilities such as the bathroom and break room. Surveillance of the tow entrance and egress is accomplished by the lock operator during travels between

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control stations and is supplemented by CCTV communication devices at strategic locations. Provision may be included for future upgrade to centralized control.

e. Control points. Additional locations for lock operations can be provided as electronic control points. These points should be either a fixed I/O panel in a watertight box or a portable I/O panel that can be plugged into a fixed outlet at the operating equipment locations. A portable notebook-size personal computer, either stand-alone or in communication with the PLC, can be used as a plug-in control

point. These control points should be located on each lock wall adjacent to the lock gates. Use of these control points should be very infrequent, usually during maintenance, repair, or emergency operation.

f. Aesthetic treatment. The architectural design of the permanent features (central control house and operations building, or local control stations) should be consistent with the form and function of the facility. However, cost efficiency should be of primary concern. In no case should additional structures be provided only to achieve architectural balance or symmetry.

Appendix B Operation of PLC Systems

B-1. Advantages of PLC System

a. General. The following operational description is typical of a lock with miter gates. Although the operational requirements may differ, locks with sector gates or lift gates can also use a PLC system.

b. Overfilling. At some locks problems exist with overfilling and overemptying of the lock chambers causing time delays and undue stress on the gates and mechanical equipment. The valves can be programmed with a PLC to start closing before the chamber is completely empty or full. The exact time when the valves begin to close could be programmed to vary with the difference between the pool and the tailwater elevations since this is what most affects the rate of filling and emptying. The speed of the valves could also be adjusted to compensate for the rate of filling and emptying at different heads. A special case could be programmed for open river conditions.

c. Improper miter/auto-emptying. Serious damage can occur to miter gates when they do not miter properly due to some obstruction or gate malfunction. If this condition occurs, it is important not to put full head on the gates. A PLC can be programmed to "crack" open the filling valves and put a small amount of pressure on the gates. If the gates do not come to a proper miter after reaching a preprogrammed head differential, the filling valves can be closed and the emptying valves opened. The operator could be given an alarm of improper miter. Such a feature is a quick programming implementation in a PLC system.

d. Lift gate control. Lift gates present special problems to navigation locks because a lift gate is hoisted from each side of the lock. The hoisting machinery has to operate synchronously to avoid skewing or "cocking" of the gate. Such fine position control and automatic skew correction can be done easily with a PLC, but would involve numerous relays, timers, and position counters in a relay system. A problem developed with the lowering of the lift gate at Melvin Price Locks and Dam. For reasons not thoroughly understood, the lift gate would occasionally get stuck in the slot. The machinery had no way of knowing that the gate had stopped. The cables continued to unreel, creating an extremely

dangerous condition of the gate being suspended while the lifting cables were lying slack on the machinery room floor. While sensors had been installed on the lifting cable sheaves to detect movement, it was never considered that the sheaves could be moving when the gate was not. Special instrumentation was placed upon the gate to detect slacking of the cables. Because of the serious nature of this problem, several redundant systems were put in place. First, slack cable limit switches were installed at a horizontal run of the lifting cables, then photocells were installed in a vertical run, and, finally, angle encoders were installed to determine movement of the counterweight sheaves. In addition, it was decided to begin lowering the gate with a small amount of head against the gate. This required constant recalculation of the head differential because of the continuously fluctuating water levels. The PLC was simply reprogrammed to accommodate the changes. The lift gate at Melvin Price has a third leaf which is essentially a movable sill. This gate is raised and lowered only infrequently under certain extreme head conditions. The PLC is programmed to automatically adjust this gate during the lockage operation so as not to cause delays to traffic.

e. Voltage drop reduction. A PLC can be programmed to stagger start motors. This reduces the simultaneous inrush current, thus reducing system voltage drop during motor starting. As a result, a savings can be realized in the sizing of system power distribution equipment.

f. Troubleshooting. Troubleshooting an RBS requires that an electrician physically move from point to point and take measurements of system parameters. This can be a hazardous and time consuming procedure. A PLC system offers the convenience and efficiency of troubleshooting the system from a personal computer. Once the nature and location of the problem is identified, an electrician usually needs only to replace a modular component and the system is back online.

g. Remote troubleshooting. With a PLC system, a systems engineer or technician with a personal computer, modem, and standard phone line can network with the PLC for troubleshooting assistance and reprogramming at any time, from any place.

h. Automation. Modern PLC's are completely capable of generating the control sequences necessary to automate lock and dam operations. Currently, only the first steps have been taken in that direction.

Melvin Price Locks and Dam has a semi-automatic lockage control system in place and operational. Following is a description of the system:

(1) The operator initializes the command PREPARE UPSTREAM END FOR ENTRY/EXIT.

(2) The PLC first checks the downstream miter gates for proper miter. If the gates are not mitered, the PLC starts the miter gates and brings them to miter. The downstream traffic light automatically goes to RED.

(3) Next, the PLC checks both emptying valves to ensure they are closed. If they are not, the PLC starts the valves and closes them.

(4) The PLC now opens the filling valves and monitors the water level in the chamber for comparison to the pool elevation. Water level indication is accomplished using a submersible pressure transmitter.

(5) To prevent overfilling of the chamber, the PLC begins closing the filling valves with about a 3-ft difference between the pool and chamber elevations.

(6) When the chamber water level reaches that of the pool, the PLC lowers the lift gate or opens the miter gates.

(7) After the vessel is completely in the lock chamber and properly secured, the operator initiates the command PREPARE DOWNSTREAM END FOR ENTRY/EXIT.

(8) The PLC first closes the upstream gates.

(9) Next the PLC checks the filling valves for closure and closes them if necessary.

(10) The PLC now opens the emptying valves. The chamber is again monitored for comparison to the tailwater.

(11) When the chamber has reached the level of the tailwater, the PLC opens the downstream miter gates.

B-2. Potential Problems of a PLC System

a. Higher skill required. The design, operation, maintenance, and modification of the PLC system will require higher skill levels. Electrical engineers and technicians will require skills associated with computer circuit design, system analysis, electronic engineering, and computer programming. Lock maintenance personnel will need to be upgraded from electricians to electronics technicians. These higher skill levels require increased compensation to attract qualified candidates.

b. Commitment. The successful installation and operation of a PLC system requires management to provide top down policy direction for financial, personnel, and training resources to successfully implement this system. The successful implementation of the PLC system requires a workforce of lock operators, lock maintenance technicians, electrical engineers, and electronics technicians who are fully committed and willing to champion this concept. If these basic requirements are not satisfied, a PLC system may not live up to expectations or could even be a bug-ridden failure.